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Hybrid chirped pulse amplification

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Abstract: A hybrid terawatt-amplification scheme combining optical-parametric-chirped-pulse amplification and amplification in active laser media is demonstrated for the first time. This simple technique uses a single pump pulse and eliminates gain narrowing, allows efficient energy conversion and does not require electro-optic devices.

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Optical parametric chirped pulse amplification (OPCPA) [1, 2] is an attractive short pulse amplification technology because of its simplicity, broad bandwidth and large gain. Pulses from a mode-locked oscillator can be amplified to mJ energies in a single pass of only 2 or 3 non-linear crystals. Furthermore, OPCPA does not intrinsically produce pre-pulses and does not require electro-optic switching to either select a single pulse from an oscillator pulse train prior to multipass amplification or to inject/eject a pulse from a regenerative amplifier. The major drawback of OPCPA, however, is pump conversion efficiency. The spatio-temporal evolution and relatively long pulse width of commercial Q-switched lasers limits conversion. The highest OPCPA extraction efficiency reported to date from a system pumped by a commercial Q-switched Nd:YAG laser is 6%. [3] It is expensive and complicated to produce an ideal pump pulse with a top hat in spatial and temporal profile. On the other hand pump to IR conversion efficiencies of >50% or 90% of the maximum theoretical quantum efficiency have been demonstrated from chirped-pulse, Ti:sapphire amplifiers pumped by commercial Nd:YAG lasers [4]. We present here the first demonstration of a simple hybrid chirped pulse amplification scheme which combines the best of both technologies.

Fig. 1 is a schematic of the hybrid chirped pulse amplification system. By using the same pump pulse to both pump an OPCPA pre-amplifier and a bow-tie Ti:sapphire multipass amplifier it is possible to achieve high overall conversion efficiency. We pump the optical parametric amplifier (OPA) at a 10-Hz repetition rate with relay imaged 7-ns, 300-mJ, 532-nm from a seeded, Q-switched, Nd:YAG laser (Spectra-Physics GCR Pro350-10). A mode-locked oscillator generates 31-nm, FWHM IR pulses centered at 820 nm. These pulses are stretched to 600 ps prior to amplification in the OPA. The OPA consists of two 15-mm long beta-barium borate (BBO) crystals, cut at $\theta=23.8^\circ$ for type I phase matching at an external noncollinear angle of 3.7° . This configuration maximizes the gain bandwidth and results in a total gain of 2.6×10^6 and 1.3-mJ amplified pulses.

A unique feature of optical parametric amplification that distinguishes it from amplification in laser gain media is the fact that no pump absorption and energy storage occurs in the OPA. Since only a small temporal slice of the pump beam is converted in the OPA, essentially the entire initial pump energy is available for pumping an additional laser amplifier. In our case, after losses on mirrors and unoptimized coatings, 200-mJ is absorbed in the multipass Ti:sapphire power amplifier. With three passes, 45-mJ, 38.5-nm FWHM pulses with excellent beam quality are obtained (Fig. 3). No significant change in the spectral FWHM was observed in the system (Fig. 2). 2 additional passes in the amplifier should produce ~100 mJ pulses. Analysis of overall system dispersion and gain bandwidth of the OPA indicates that multiterawatt pulses in the 10-fs range can eventually be produced with this technique.

Our system demonstrates the successful use of hybrid architecture based on BBO and Ti:sapphire which does not require electro-optic modulators and exhibits superior energetic performance when compared to a system based on OPA alone and superior bandwidth and simplicity when compared to a system based on Ti:sapphire alone. The demonstrated 15% conversion efficiency is highest to date in an OPA-based CPA system pumped by a tabletop pump laser. 40% conversion should be possible with planned optimization of the multipass amplifier.

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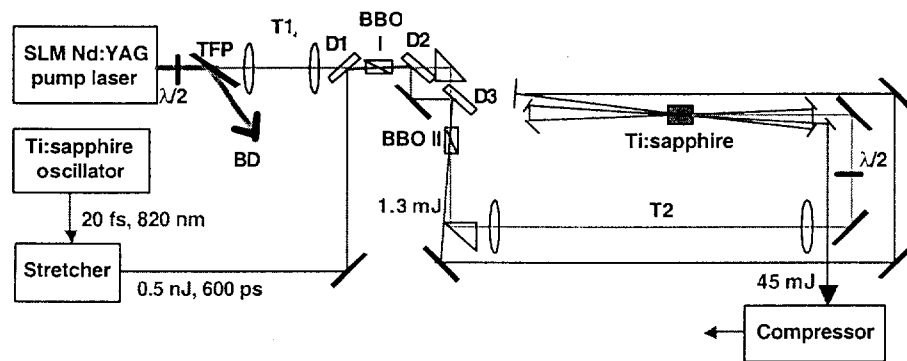


Fig. 1. Experimental setup. TFP-thin film polarizer, T-telescope, D-dichroic.

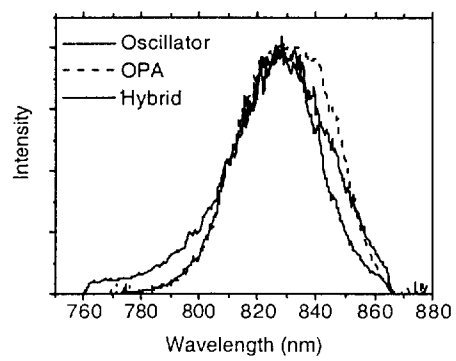


Fig. 2. Seed and amplified signal spectra from the OPA and Ti:sapphire amplifier

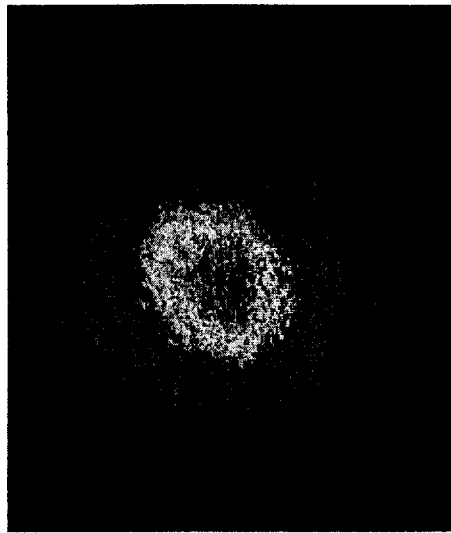


Fig.3. Beam profile of the amplified pulse